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ON THE DISRUPTION OF THE RECIPROCITY PRINCIPLE DURING THE DAYTIME PROPAGATION OF SUPER LONG RADIOWAVES AROUND THE EARTH

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SUMMARY

The disruption of the reciprocity principle during the daytime propagation of super-long radiowaves around the Earth is discussed on the basis of the so called valve effect taking place in daytime near the equatorial region. As in the preceding work on the general boundary value problem, the principal author bases this work on earlier ones, mostly by himself. However, here some problems of aeronomy are involved.

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1. Experiments [1 - 4] have established that the damping of super-long waves (slw) on courses proceeding from east to west is greater than in the opposite direction. This, so called "valve effect" is particularly great in daytime courses, close to the geomagnetic equator. It is caused by ionosphere anisotropy [5 - 8] and also by the magnetized transverse magnetic field, analogously to the valve effect taking place in shf-waveguides with ferrite [9]. In the waveguide theory of s.l.w. it was disregarded [10-12]. This, however, may be done in a natural fashion if during the calculation of ionosphere impedances by the method of [13], entering into the equations for wave numbers of normal waves, we take into account not only the vertical component of the Earth's magnetic field H_r, but also the horizontal ones, H_θ (along the course) and H_ϕ (across it). The scarce data on the valve effect in s.h.w. do not permit the application of the method of data coordination on the field and the medium [10 - 12]. This is why we shall take for a first approximation the profiles of electron concentration $N_e(h)$ and the collision frequencies $\nu_{eff}(h)$, obtained without taking into account the valve effect, corrected for the equatorial zone by aeronomical calculations [14] by introducing them concomitantly with H_θ, H_ϕ and H_r into the tensor of ionosphere dielectric constant (ε).

(*) O NARUSHENII PRINTSIPA VZAIMNOSTI PRI RASPROSTRANENII SVERKHDLINNYKH RADIOVOLN VOKRUG ZEMLI V DNEVNOYE VREMYA

The components of tensor ε_{jk} (i, j, k being the orts with respect to θ, ϕ and r) are

$$\varepsilon_{ij} = \pm \frac{ivU_k}{Z^2 - U^2} + \frac{vU_iU_j}{Z(Z^2 - U^2)} (i \neq j); \quad \varepsilon_{ii} = 1 - \frac{v}{Z} - \frac{vU^2_{jk}}{Z(Z^2 - U^2)} (i = j), \tag{1}$$

where $v = 4\pi N_e(h) e^2 / m\omega^2$; $Z = 1 + i\nu_{eff}(h) / \omega$; $U_j = -eH_j / mc\omega$, $\vec{j}$ is ort θ (ϕ or r), $\vec{U} = U_i\mathbf{i} + U_j\mathbf{j} + U_k\mathbf{k}$; U_{jk} is the projection of $\vec{U}$ on the plane with orts j, k; the sign + is taken when i, j in ε_{ij} stand in the order θ, ϕ, r; H_θ, H_ϕ and H_r are the components of $\vec{H}_0$ in a system of coordinates linked with the course of the wave: its origin is on the polar axis.

2. For a course proceeding along the geomagnetic equator, only H_θ is not zero and the system of Maxwellian equations for the ionosphere (4) of [13] breaks up into purely TH- and purely TE-waves. For the TH-waves of interest to us the impedance Eq.(9) of [13] assumes the simple form:

$$\left(\frac{\varepsilon_{\theta\theta}}{\Delta} u\right)'_r + \frac{\varepsilon_{\theta\theta}}{\Delta} u^2 + k^2 \left[1 - \frac{\varepsilon_{\theta\theta}}{\Delta}\left(\frac{\nu}{kr}\right)^2 \pm \frac{ir}{k}\left(\frac{\varepsilon_{\theta r}}{r\Delta}\right)'_r \left(\frac{\nu}{kr}\right)\right] = 0, \tag{2}$$

where $\Delta = \varepsilon_{\theta\theta}^2 + \varepsilon_{\theta r}^2$. The last term of (2) is responsible for the disruption of the reciprocity principle and the valve effect linked with it. Integration of (2) over r from $r_\infty = c + h_\infty$, where u assumes the adiabatic value

$$\bar{u}^e(r_\infty) = ik\sqrt{\varepsilon_{\theta\theta} + \frac{\varepsilon^2_{\theta r}}{\varepsilon_{\theta\theta}} - \left(\frac{\nu}{kr_\infty}\right)^2}, \tag{3}$$

to the point r = c, where u(c) gives the impedance $Z_y{}^e = iu(c)/k$, entering in the equation

$$\overline{D_\nu(a', c')} - iZ_y{}^e\overline{D_\nu(a', c)} = 0, \tag{4}$$

of which the roots are the wave numbers of type-TH normal waves. It is obtained from (14) of [13] on the condition that $X^e = 0$. The excitation coefficients are determined from formula (13) of [12].

3. We shall demonstrate that the calculation of TH-wave parameters for any daytime courses on Earth may be conducted with sufficient precision using formulas of the preceding section 2. To that effect we shall break down the integration interval (r_∞, c) of Eqs.(9) of [13] in two : (r_∞, d) where the adiabatic approximation and (d,c), where storage of radiowave reflections takes place, are valid. The point r = d may be defined by comparison of hodograph of $\mathbf{u}(r)$ of Eq.(9) from [13] with that of the adiabatic approximation $\bar{u}(r)$ of Eq.(10) of ref.[13]; r = d depends on ν, $\vec{H}_0$ and on profiles of $N_e(h)$ and $\nu_{eff}(h)$. We shall call the $N_e(h)$ profile as <u>diurnal</u> if for ν near <u>ka</u> and any $|\vec{H}_0| \leqslant 0.5$ oe the condition Z(d) > U is satisfied. On the strength of adiabaticity of (r_∞, d), we shall transfer the origin of integration from r_∞ to <u>d</u>. Eq.(10] of [13], determining $\bar{u}(d)$ is approximated by a biquadratic equation when the diurnal profile condition is fulfilled. One of its roots coincides with u^e, determinable from (3) at r = d.

Since the profile of ν_{eff} has the form

$$\nu_{eff} = s_0 10^5 \exp\left[-0{,}148\,(h-89)\right], \tag{5}$$

where s_0 = 5 - 10, h = r - a in km, it follows that for Z(d) > U this inequality is also fulfilled for all r < d. By virtue of this, Eq,(9) of [13] for impedances $Z_y{}^e$ of TH-waves at any H_θ, H_ϕ and $H_r \leqslant 0.5$ oe is approxmiated by (2). Confirmation of this important result simplifying the correction of the theory [10 - 12], is given in Fig.1, where hodographs u(r), obtained by integration of (9) from ref.[13] for f = 15 khz, ν = 2000 are plotted for the profile of $N_e(h)$ of middle latitudes (curve 1 of Fig.1). Substituting $N_e(h)$ and $\nu_{eff}(h)$ by echelon profiles with jumps at points h_0, h_1, ..., h_l, h_{l+1},h_d hodograph u(r) may be represented by piecewise-continuous curve undergoing a jump at each step h_l assuring the continuity of $Z_y{}^e$ according to Eq.(11) of ref.[13]

$$Z_e(h_l) = \frac{1}{\Delta}\left[\frac{\varepsilon_{\theta\theta}}{ik}\,u^e(h_l) \mp \varepsilon_{\theta r}\frac{\nu}{kr_l}\right], \quad r_l = a + h_l. \tag{6}$$

Between steps, the hodograph moves along a circumference, of which the radius depends on the stored reflection factor in the overlying layers. Hodograph A is constructed for H_θ = H_ϕ = 0 and H_r = 0,445 oe. Hodograph B is plotted for H_θ = H_ϕ = H_r = 0. According to the aforementioned considerations, their terminal values u(c) coincide despite the strong distinction of the initial ones: the accumulation of reflecttion takes place only at the expense of the first term of (6). In hodographs Г and Д , H_θ = H_r = 0, and H_ϕ = 0.445 oe, and the 2nd term of (6) introduces a different effect of reflecton accumulation, as a function of the choice of wave direction ν > 0 (W → E) or ν < 0 (E → W). **Б** is a case similar to A, but for the ordinary wave only.

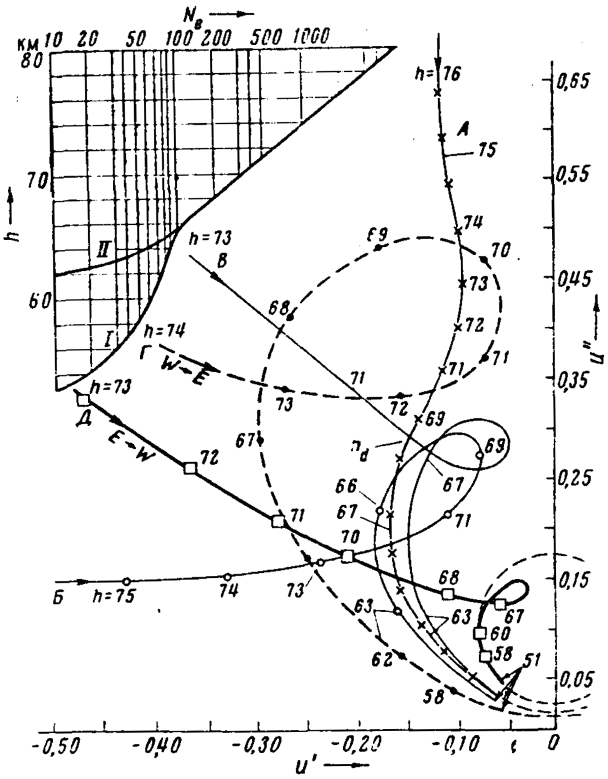

Fig.1

Hodographs u(h) and profiles of electron concentration $N_e(h)$

4. Plotted in Figures 2 and 3 are the computations of damping coefficients $\beta(TH_1)$ and of differences in the angular wave numbers $\Delta\alpha(TH_1) = \alpha(H_\phi) - \alpha(0)$, performed as a function of frequency f and H_ϕ, using an electronic computer, for two types of profiles: I representing the middle latitudes in summer and II representing the equatorial zone (Fig.1) at $s_0 = 5$ and $s_0 = 10$*). Indicated on the curves $\beta(f)$ and $\Delta\alpha(f)$ are the values of H_ϕ, s_0 and the type of profile. To the right dampings are given in db and plotted in ordinates for 1000 km. The computations were conducted according to formulas of sec.2

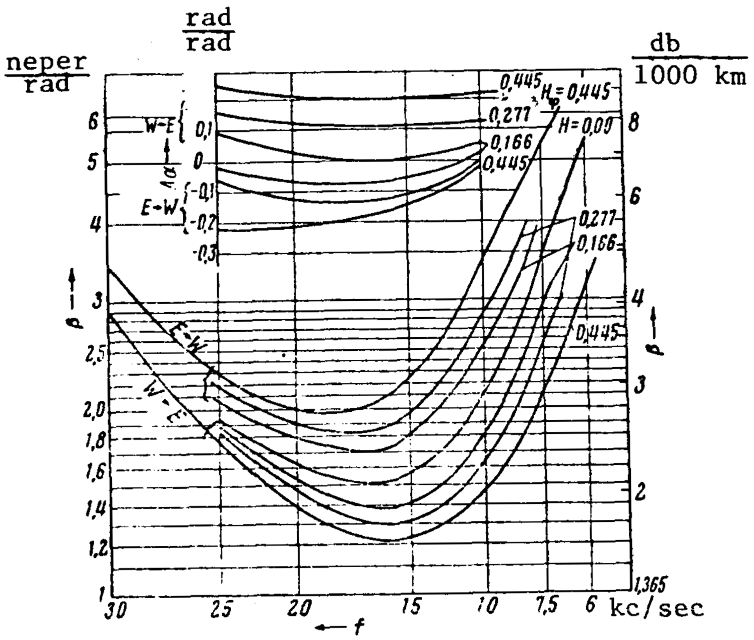

Fig.2. Parameters $\beta(f)$ and $\Delta\alpha(f)$ of the wave TH_1 for the $N_e(h)$ profile I of middle latitudes at $s_0 = 5$

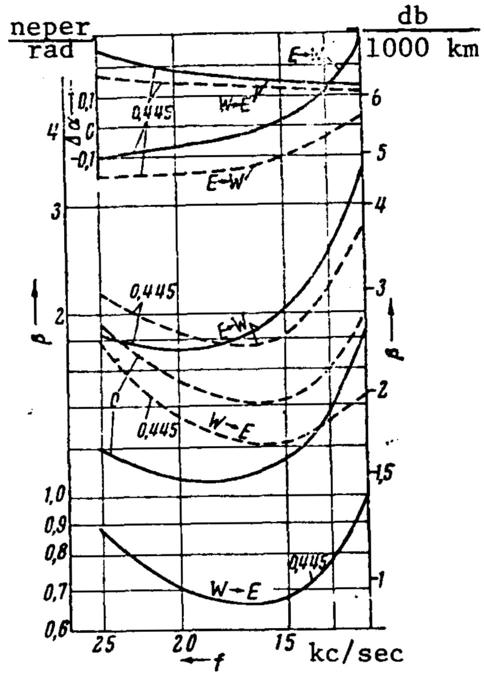

Fig.3. Parameters $\beta(f)$ and $\Delta\alpha(f)$ of the TH_1-wave for the profile I, $s_0 = 10$ (dashed curves) and profiles II, $s_0 = 5$ (solid lines). The values of H_ϕ equal to 0.445 and 0 are indicated on the curves

but, on the strength of the assertion of sec.3, they are applicable for any diurnal courses. Profile I is applicable for latitudes $|\phi| > 40°$, and profile II for $|\phi| < 20°$. In the intermediate zone $20° < |\phi| < 40°$, β and $\Delta\alpha$ are estimated by mean values. The values of $\alpha(0)$ may be borrowed from the corresponding graphs for $\alpha(f)$ of ref.[10 - 12]. If $H_r = \sqrt{H_\varphi^2 + H_\theta^2}$ is the total horizontal component of the field $\vec{H}_0$ at the given point of the course, and ψ is the angle between $\vec{H}_r$ and the course, β may be determined for it approximately by formula $\beta = \beta(H_r)\sin\psi$, where $\beta(H_r)$ will be obtained from either Fig.2 or 3 by interpolation. It may be seen from Figs. 2 and 3 that in the equatorial zone the valve effect attains highest values. Thus, for example, for f = 10 kc/sec it follows that on the course Panama Canal - Hawaii of 1.33 rad. extension, where the mean value $H_\phi = 0.3$ oe (profile II, Fig.3), $\beta(W, E) = 1.2$ neper/rad, and $\beta(E, W) = 2.9$ neper/rad, whence the ratio of field intensities is $P = \exp[\beta(E, W) - \beta(W, E)]\theta \cong 10$, which is close to the experimental value of 12.3 obtained in the work [3]. At middle latitudes the valve effect is attenuated at the expen e of the appearance of layer C induced by cosmic rays [11, 12, 14] and the decrease of H_ϕ. Over summer transatlantic courses, where $H_\phi \cong 0.15$ oe, for f = 15 kc/sev, β(E, W) = 1.75 neper/rad, β(W, E) = 1.4 neper/rad, which gives P = 1.4 for θ = 1 rad. In winter daytime computation gives β(E, W) = 2.8, β(W, E) = 2.1, and for θ = 1 rad we shall obtain P = 2.5. These results are close to the experimental ones of the round-the world expedition of 1922 - 1923 [4]. The valve effect is weakened with the rise of atmospheric pressure because of ν_{eff} increase (see graphs of Figs. 2-3 for s_0 = 5; s_0 = 10) and with the increase of frequency f. The results of calculations for the profiles I and II are a good corroboration of the fact that the C-layer is practically absent in the equatorial zone, as this is required by the aeronomical theory of origin of the C-layer. at the expense of primary cosmic rays. Had the C-layer existed in the equatorial zone, and if the N_e profile were close to profile I, the calculated P would have been equal to 5, which is significantly below the experimental value of 12. In nighttime all the three components of the field, H_θ, H_ϕ, H_r have to be taken into account for the registration of the valve effect.

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